NUWC-NL Technical Document 10,229
11 December 1992

(12)

The Influence of a Bubbly Layer on Near-Surface Acoustic Propagation And Surface Loss Modeling

A Paper Presented at The 124th Meeting Of the Acoustical Society of America 31 October 1992, New Orleans, Louisiana

Raymond J. Christian
Environmental and Tactical Support Systems Department

Naval Undersea Warfare Center Detachment
New London, Connecticut

Approved for public release; distribution is unlimited.

PREFACE

This document was funded under NUWC Project No. B10003, Principal Investigator R. J. Christian (Code 3112). The sponsoring activity is the Office of Naval Technology, Program Manager Dr. G. Kovalenko (Code 20P21). The original research for this document was completed under NUWC Project No. D20026, *Multistatic Sonar Project*, Principal Investigator R. J. Christian (Code 3112) and Program Manager C. D. Mason (Code 304). The sponsoring activity was the Naval Sea Systems Command, Program Manager D. Spires (PEO USW ASTO-C1).

The author is grateful for the many helpful comments of J. M. Tattersall (Code 3112).

REVIEWED AND APPROVED: 11 DECEMBER 1992

B.F. Cole

B. F. Cole
Head, Environmental and Tactical Support Systems Department

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
11 December 1992

3. REPORT TYPE AND DATES COVERED
Presentation

4. TITLE AND SUBTITLE
The Influence of a Bubbly Layer on Near-Surface Acoustic Propagation and Surface Loss Modeling

5. FUNDING NUMBERS
PE 602936
PR RV36I22

6. AUTHOR(S)
Raymond J. Christian

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Undersea Warfare Center
Detachment New London
New London, CT 06320

8. PERFORMING ORGANIZATION REPORT NUMBER
TD 10,229

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Sea Systems Command
Washington, DC 20362-5101

Chief of Naval Research
Arlington, VA 22203

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The impact of refraction, attenuation, and scattering due to a near-surface bubbly layer on acoustic propagation modeling can be significant in sensitive surface duct and shallow water environments. Hall (J. Acoustic. Soc. Am. 86(3), September 1989) presents a semi-empirical acoustic model to determine the propagation effects of the bubbly layer on one-way horizontal transmission in a surface duct. Expressions for the depth-dependent complex sound speed and attenuation are used to extend the Hall model to the general near-surface acoustic interaction problem. The rough surface scattering at the air-sea interface and the propagation through the subsurface bubbly layer are treated independently in a simplified approach toward examining the impact of bubbles on modeled surface duct and shallow water transmission loss. The dependence of the "effective" surface loss on grazing angle and wind speed is analyzed in the frequency band of approximately 0.5-5 kHz.

14. SUBJECT TERMS

Attenuation	Damping	Shallow Water
Bubbles	Grazing Angle	Surface Duct
Bubbly Layer	Refraction	Surface Loss

15. NUMBER OF PAGES
26

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

VIEWGRAPH 1

NUWC

THE INFLUENCE OF A BUBBLY LAYER ON NEAR-SURFACE ACOUSTIC PROPAGATION AND SURFACE LOSS MODELING

RAYMOND J. CHRISTIAN

NAVAL UNDERSEA WARFARE CENTER
DETACHMENT NEW LONDON
NEW LONDON, CT 06320

Many studies have investigated the role of near-surface bubbles in ambient noise generation, acoustic backscatter, and transmission loss. Medwin,[1] Novarini and Bruno,[2] and Hall[3] have addressed the impact of bubbles for the special case of surface duct propagation. Hall has developed a comprehensive semi-empirical acoustic model that incorporates the bubble measurements of Johnson and Cooke[4] and Thorpe.[5] Hall's model lends itself toward studying the impact of a bubbly layer on the general surface loss problem. Transmission loss for acoustic environments that involve many surface interactions (e.g., shallow water and surface duct) is particularly affected by propagation loss at the near-surface boundary. Thus, the inclusion of near-surface bubbles in the acoustic propagation problem is seen as a necessary requirement in ensuring that all mechanisms at the surface boundary are properly addressed. This study will examine the impact of the bubbly layer on acoustic propagation in the 0.5- to 5-kHz frequency regime.

VIEWGRAPH 2

NUWC

BACKGROUND

- A HOST OF STUDIES HAVE SHOWN THE INFLUENCE OF NEAR-SURFACE BUBBLES ON AMBIENT NOISE, ACOUSTIC BACKSCATTER AND TRANSMISSION LOSS. HALL (J. ACOUST. SOC. AM. VOL. 86, NO. 3, SEPTEMBER 1989) HAS DEVELOPED A COMPREHENSIVE ACOUSTIC MODEL BASED ON EMPIRICAL MEASUREMENTS OF BUBBLE POPULATIONS INVESTIGATING ONE-WAY SURFACE DUCT PROPAGATION LOSS AS A FUNCTION OF SOURCE DEPTH.

- HALL'S MODEL IS EXTENDED TO EXAMINE THE INFLUENCE OF THE BUBBLY LAYER ON NEAR-SURFACE PROPAGATION AND RESULTING IMPACT ON SURFACE LOSS MEASUREMENTS AND MODELING

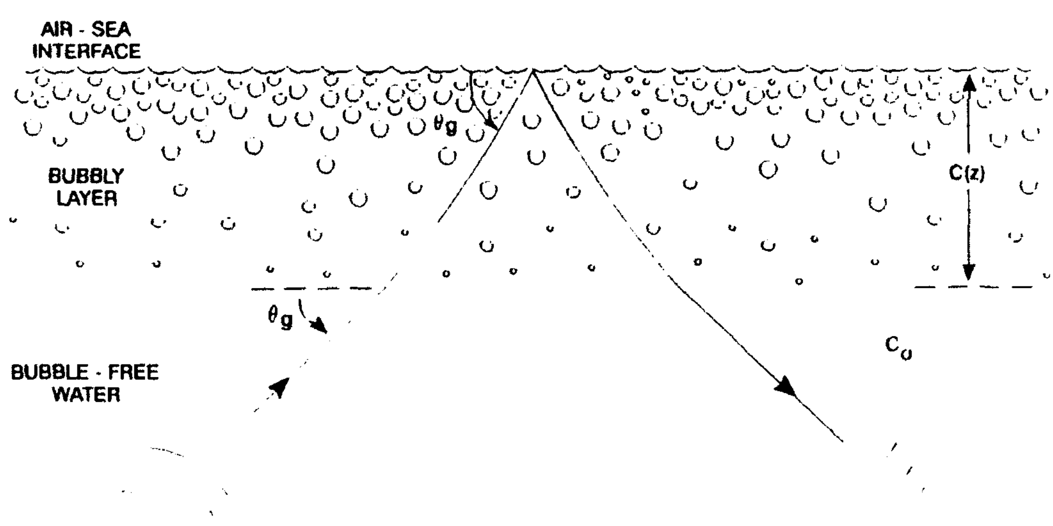
Theoretical studies of the acoustic reflection loss at the air–sea boundary generally neglect the influence of the near–surface bubbly layer. The present analysis addresses the impact of refraction and absorption on the acoustic wave just before and after the interaction with the sea surface. The objective is to examine the relative contribution of the bubbly layer to the total near–surface loss as a function of grazing angle, wind speed, and frequency.

This study will apply ray theory to the sound propagation near the surface. In the viewgraph, the bubbly layer is modeled to result in (1) a depth–dependent sound speed (C(z)) yielding a change in grazing angle (from θ_g to θ_g') and (2) absorption along the acoustic path length.

VIEWGRAPH 3

NUWC

NEAR - SURFACE PROPAGATION IN A BUBBLY LAYER



To simplify the problem, this study is based on the following assumptions:

1. The existence of a horizontally stratified layer of bubbles without inhomogeneities in the bubble population density. Future work in this area will address Langmuir "banding" and bubble plume distributions.

2. The absence of scattering effects due to the frequencies examined being low enough to result in a very small product for the acoustic wavenumber k_a and the bubble radius a.

3. No contribution to the surface-scattered field from off-specular reflections.

4. The exponential decay of the sound speed anomaly at the surface. It will be shown that this assumption is supported by measurements. It has been found that invoking the first assumption results in negligible bubble effects below 10 m. When bubble plume dynamics are considered, it is expected that depths greater than 10 m will need to be addressed.

5. No orbital motion and other turbulence due to surface waves in the bubbly layer.

VIEWGRAPH 4

NUWC

ASSUMPTIONS

1. BUBBLE DENSITY IS AZIMUTHALLY HOMOGENEOUS FOR A GIVEN DEPTH. LANGMUIR MECHANISM (BANDING) IS NEGLECTED.
2. SCATTERING DUE TO BUBBLES IS NEGLECTED ($k_a\, a \ll 1$).
3. INCOHERENT, OFF-SPECULAR SEA-SURFACE SCATTERING IS NEGLECTED. SURFACE LOSS MODELS ARE ROUGH-SURFACE ACOUSTIC SCATTERING MODELS.
4. DEPTH DEPENDENCE OF THE SOUND SPEED ANOMALY AND ATTENUATION DUE TO BUBBLES CAN BE APPROXIMATED BY AN EXPONENTIAL DECAY. BUBBLE EFFECTS ARE NEGLECTED AT DEPTHS $>$ 10m.
5. THE EFFECTS OF SEA-SURFACE MOTION ON THE BUBBLY LAYER ARE NEGLECTED.

The Hall model is extended to obtain closed-form expressions for the sound speed anomaly and attenuation as functions of frequency, depth, and wind speed. The sound speed anomaly is used with Snell's law to determine the total refractive effect, and the new acoustic wave direction (θ'_g) is used in the rough surface scatter model to be implemented. Rough surface scattering is treated as independent of the bubbly layer. The total attenuation is found through numerical integration over the acoustic path length before and after the surface reflection. Small uncertainties in the near-surface boundary loss can result in large transmission loss uncertainties for multiple surface-interaction propagation environments. The effects of the bubbly layer may be small at lower frequencies (~0.5–1.0 kHz), but should still be examined for accurate modeling of such environments.

VIEWGRAPH 5

NUWC

APPROACH

- EXTEND HALL MODEL TO OBTAIN SOUND SPEED ANOMALY AND ATTENUATION AS FUNCTIONS OF FREQUENCY, DEPTH AND WIND SPEED. DERIVE CLOSED-FORM EXPRESSIONS.
- NUMERICALLY INTEGRATE OVER ACOUSTIC PATH LENGTH TO DETERMINE TOTAL REFRACTION AND ATTENUATION AS A FUNCTION OF GRAZING ANGLE AND WIND SPEED.
- DETERMINE "EFFECTIVE" SURFACE LOSS DUE TO BUBBLE ATTENUATION AND ROUGH SURFACE SCATTERING.
- PERFORM MODEL VALIDATION OF SURFACE LOSS AND PROPAGATION LOSS WITH EMPIRICAL DATA COLLECTED IN SURFACE DUCT AND SHALLOW WATER ENVIRONMENTS.

The complex sound speed in the bubbly layer (C) is found by evaluation of the integral for all bubble radii (a). Hall models the bubble population density spectrum level by an empirical fit to the Johnson and Cooke measurements[4] and Thorpe.[5] The real part of C, Re(C), yields the sound speed anomaly, and the imaginary part of C, Im(C), is used to compute the attenuation. Damping occurs primarily from thermal diffusion for the low frequencies of this study.[6]

VIEWGRAPH 6

NUWC

COMPLEX SOUND SPEED

$$\frac{1}{C^2} = \frac{1}{C_o^2} + \frac{1}{\pi f^2} \int_0^\infty \frac{a\,N(a)}{\left(\frac{a_r}{a}\right)^2 - 1 + i\delta}\,da \qquad (1)$$

where

N(a) = BUBBLE POPULATION DENSITY SPECTRUM LEVEL
C_o = SPEED OF SOUND WITHOUT BUBBLES
δ = DAMPING COEFFICIENT
a^r = RESONANT RADIUS (AT FREQUENCY f)
a = BUBBLE RADIUS
f = FREQUENCY (kHz)

The sound speed anomaly ($Re[C] - C_o$) is expressed in equation (2). The $\sqrt{f}$ and w^3 dependence is obtained directly from reference 3. Hall noted that the depth dependence of the anomaly is approximately an exponential decay. The depth dependence is found to have a decay constant, m(w), that is dependent on wind speed. The wind speed dependence shown in equation (3) was determined using a least-squares fit to the sound speed anomaly generated from equation (1) for the range of wind speeds (0-20 m/s) at 1.25 kHz. A check of the validity of the below expression is done by comparison with the measurements of Farmer and Vagle.[7]

VIEWGRAPH 7

NUWC

SOUND SPEED ANOMALY

HALL INTEGRATION RESULTS SHOW THAT DEPTH DEPENDENCE OF THE SOUND SPEED ANOMALY CAN BE APPROXIMATED BY AN EXPONENTIAL DECAY:

$$Re[C] - C_o = 33\left(\left(\frac{f}{60}\right)^{\frac{1}{2}} - 1\right)\left(\frac{w}{15}\right)^3 e^{m(w)\cdot z} \qquad (2)$$

where

$$m(w) = .0078w^2 - 0.33\,w + 4.36 \qquad (3)$$

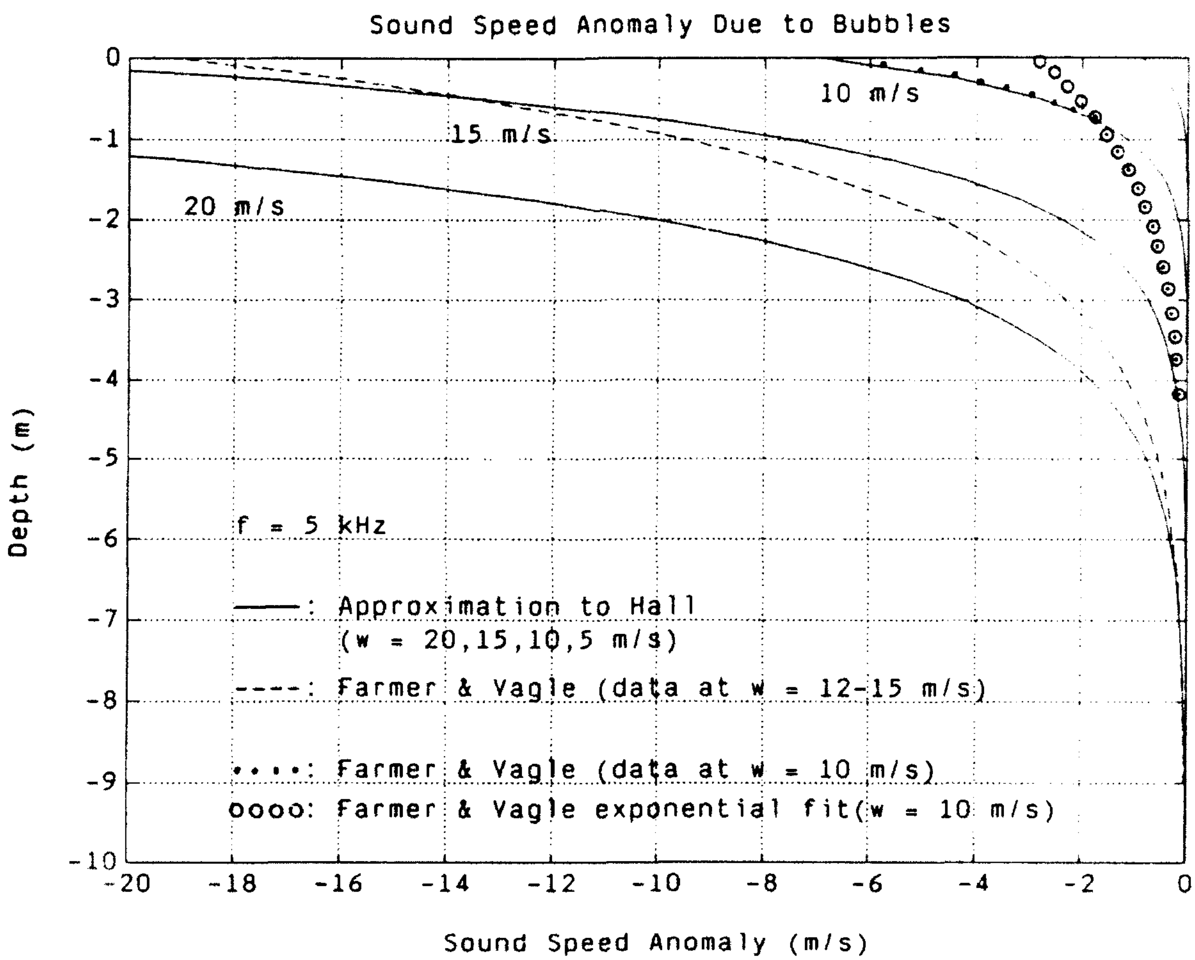
w = WIND SPEED (m/s)
z = DEPTH (m)

COMPARISON WITH FARMER AND VAGLE (JASA, 86(5), NOV 1989) AT 5 kHz SHOWS REASONABLE AGREEMENT.

Measurements by Farmer and Vagle are done at 5 kHz for two different wind speed conditions (10 m/s and 12–15 m/s). Reasonable agreement between the data and the approximation to Hall is seen for both wind speeds. The sound speed anomaly data at the lower wind speed are shown to split to ~–5 m/s and –3 m/s at the surface (z = 0). The data collected by Farmer and Vagle are represented by the lower values (~–5 m/s), and the exponential fit to the data derived by reference 7 results in the higher values (–3 m/s).

VIEWGRAPH 8

NUWC



The rate of attenuation, α, is found from equation (4) after evaluation of the complex sound speed. The approximation to α yields a quadratic dependence of frequency and an exponential dependence of depth with a decay constant of $(1/2)(\sqrt{w/15})(1/L(w))$, where $L(w)$ is the e-folding depth of the bubble population density spectrum level $N(a)$. $L(w)$ is empirically fit by Hall and given by the bilinear curve

$L(w) = 0.4$	(m)	$w \leq 7.5$ m/s
$0.4 + 0.115\,(w - 7.5)$		$w > 7.5$ m/s.

The frequency dependence differs slightly from Hall due to the inclusion of lower frequencies (0–5 kHz) in the quadratic approximation (least-squares fit).

VIEWGRAPH 9

NUWC

RATE OF ATTENUATION

$$\alpha = -\left(\frac{20}{\ln 10}\right) 2\pi f \,\mathrm{Im}\left(\frac{1}{C}\right) \tag{4}$$

OBTAIN α FROM HALL INTEGRATION RESULTS. FIT FREQUENCY DEPENDENCE WITH QUADRATIC POLYNOMIAL AND APPROXIMATE DEPTH DEPENDENCE WITH EXPONENTIAL DECAY:

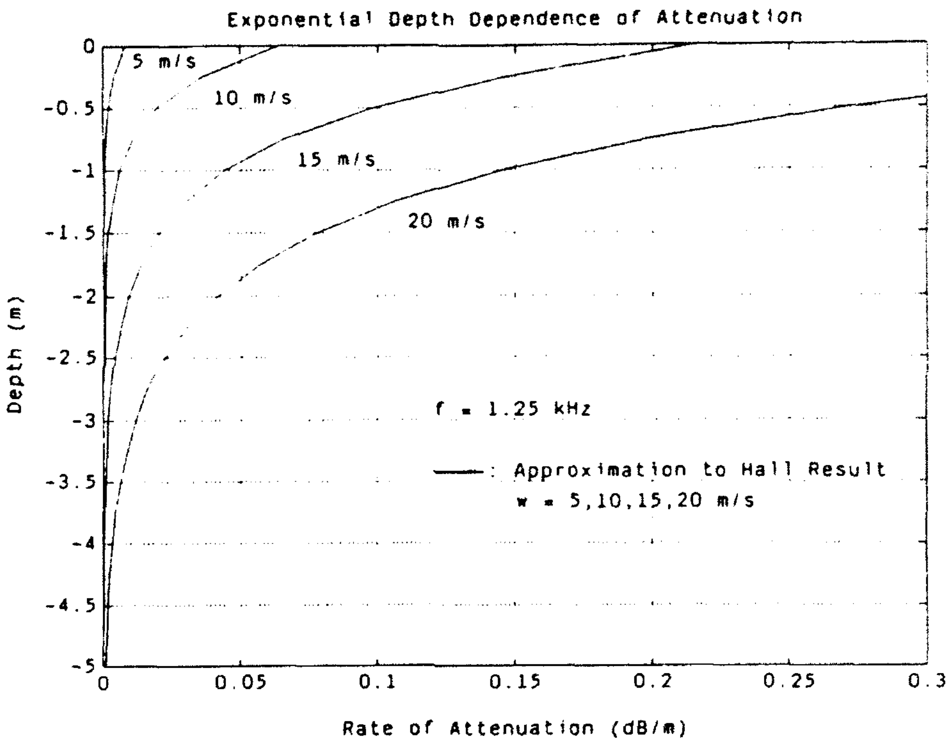
$$\alpha \cong \left(.0061\ f^2 + .2066\, f - .0521\right)\left(\frac{w}{15}\right)^3 e^{\left(2\ \sqrt{\frac{w}{15}}\ \frac{z}{L(w)}\right)}\ , \tag{5}$$

WHERE α IS IN dB/m.

The rate of attenuation showing the exponential depth dependence is plotted at a frequency of 1.25 kHz. It is noted that the rate of attenuation is relatively small for even large wind speeds, but when the total attenuation is found by integration over the acoustic path length, the impact can be significant at low grazing angles.

VIEWGRAPH 10

NUWC



The total or "effective" near-surface loss is modeled to consist of the following two independent components:

1. The rough surface scattering term (SL_r), where the grazing angle utilized (θ'_g) is a result of refractive effects of the bubbly layer and

2. The integrated attenuation loss term (SL_a), where the rate of attenuation, α, is integrated over the acoustic path length before and after the interaction with the surface.

VIEWGRAPH 11

NUWC

"EFFECTIVE" NEAR-SURFACE LOSS

$$SL = SL_r + SL_a \qquad \text{(dB)}$$

where SL_r = **ROUGH SURFACE REFLECTION LOSS WITH INCIDENT GRAZING ANGLE** θ'_g **INCORPORATING REFRACTION EFFECTS DUE TO BUBBLES.**

$$\theta'_g = \cos^{-1}\left[\cos(\theta_g)\cdot\left(\frac{\mathrm{Re}(C)\ - C_o}{C_o} + 1\right)\right]$$

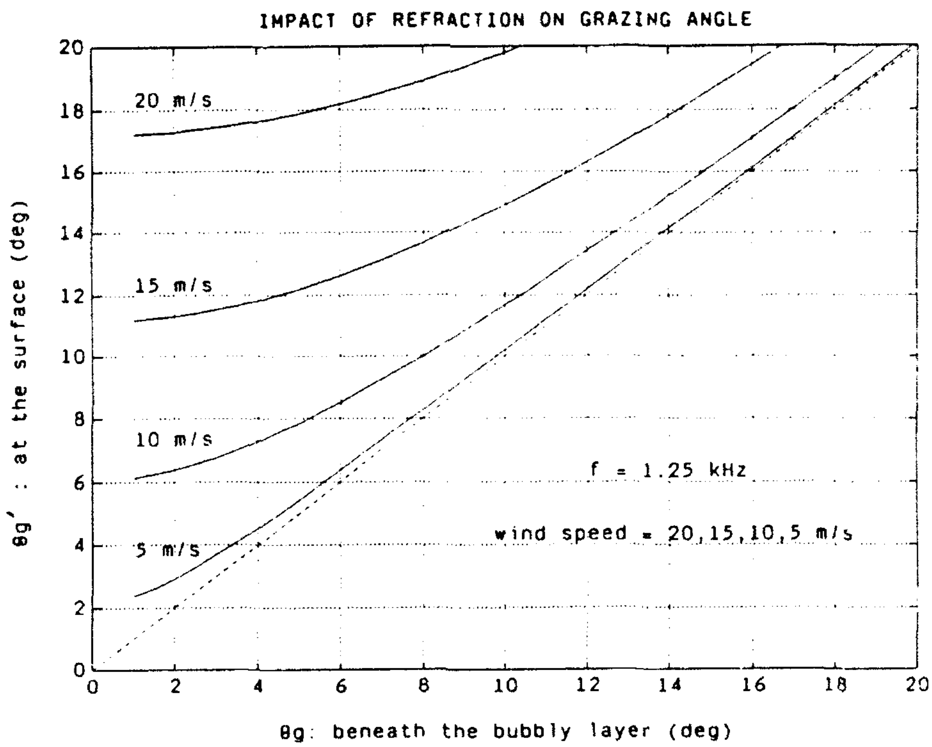
SL_a = **INTEGRATED ATTENUATION LOSS DUE TO A BUBBLY LAYER.**

$$= 2\cdot\int_{z/C_o}^{z=0} \alpha(z)\csc[\theta(z)]\,dz$$

The wind speed dependence of refraction is shown by comparison of the grazing angle of the acoustic wave at the bottom of the bubbly layer (θ_g) with the grazing angle at the surface (θ'_g). At very low grazing angles associated with surface duct propagation ($\theta_g < 2°$), it is seen that even a moderate wind speed of 10 m/s can triple the grazing angle to ~6°. Shallow water propagation can have grazing angles that are typically less than 10°, and it is seen that at moderate wind speeds (15–20 m/s), there is a significant increase in the grazing angle relative to the bottom of the bubbly layer. This plot shows that even in the absence of attenuation, refractive effects alone will result in a flattening of the grazing angle dependence of the near-surface reflection loss. Similar results are seen in reference 8, where the grazing angle distribution of an acoustic pressure field shifts to higher angles when a bubbly layer is introduced.

VIEWGRAPH 12

NUWC



A power law fit is applied to the integrated attenuation. The result provides a closed-form expression that brings out the dependence on wind speed, grazing angle, and frequency. The limit of application of the equation is for $\theta_g > 2°$ and $w < 20$ m/s. The quadratic fit for f does not exhibit appreciable error above ~0.5 kHz.

VIEWGRAPH 13

NUWC

INTEGRATED ATTENUATION (SL_a)

INTEGRATE ATTENUATION OVER ACOUSTIC PATH LENGTH BEFORE AND AFTER SURFACE REFLECTION AT AIR-SEA BOUNDARY. RESULTS CAN BE APPROXIMATED BY A POWER LAW FIT IN W AND θ.

$$SL_a \cong (.0375\, f^2 + 1.2968\, f - .320) \cdot \theta^a \cdot 10^{b+c}$$

where

$$a = .0019\, w^2 + .1348\, w - 1.8612$$

$$b = -.0047\, w^2 + .1869\, w - 1.24$$

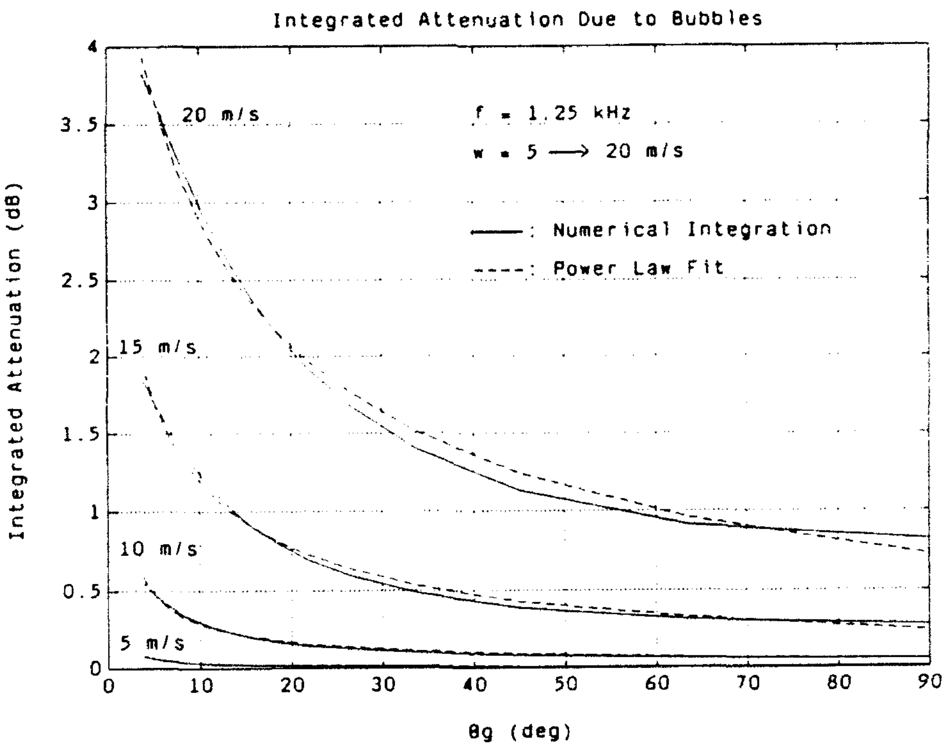
$$c = (.0009\, w^2 - .0483\, w + .3582) \cdot (\log(\theta))^2$$

θ = grazing angle (deg)
f = frequency (kHz)
w = wind speed (m/s)

The integrated attenuation due to bubbles (SL_a) is plotted for both the numerical solution and the power law fit. The interesting result is the increase in attenuation with decreasing grazing angle and increasing wind speed. Although the integrated attenuation is small for the 1.25-kHz example shown, the loss can be seen to be significant for many surface interactions associated with a surface duct or shallow water environment. Also, relative to rough surface scattering theories (e.g., Kirchhoff, perturbation . . .), where the surface reflection loss approaches zero at zero degrees grazing angle, the SL_a is an important term to reconcile in modeling and measuring near-surface propagation.

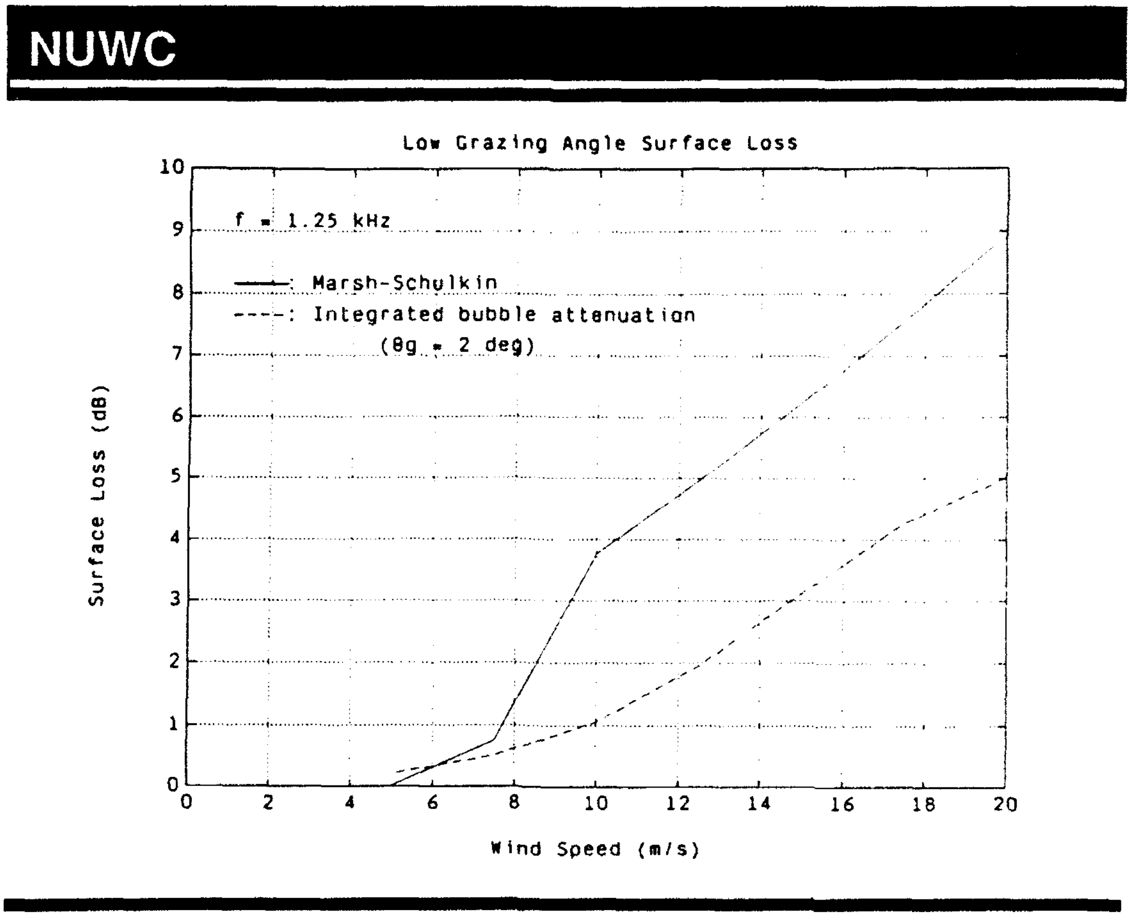
VIEWGRAPH 14

NUWC



A comparison of the integrated bubble attenuation (SL_a) is made with the loss associated with the limiting ray cycle of the surface duct measurements of Marsh and Schulkin[9] as implemented by Weinberg.[10] The data and the SL_a modeling results show that at moderate to low wind speeds (w < ~8 m/s), the Marsh–Schulkin loss can be explained exclusively by the mechanism of attenuation in a near-surface bubbly layer. There is an ~3-dB difference between SL_a and the empirical data for w > 10 m/s. This difference suggests that the modeling needs to address either (1) a loss at the air–sea boundary (SL_r) at higher wind speeds or (2) a greater attenuation loss (perhaps due to bubble clouds or plumes).[11] The attenuation loss implies that the stratified layer assumption of the model may need to be relaxed at the higher wind speeds.

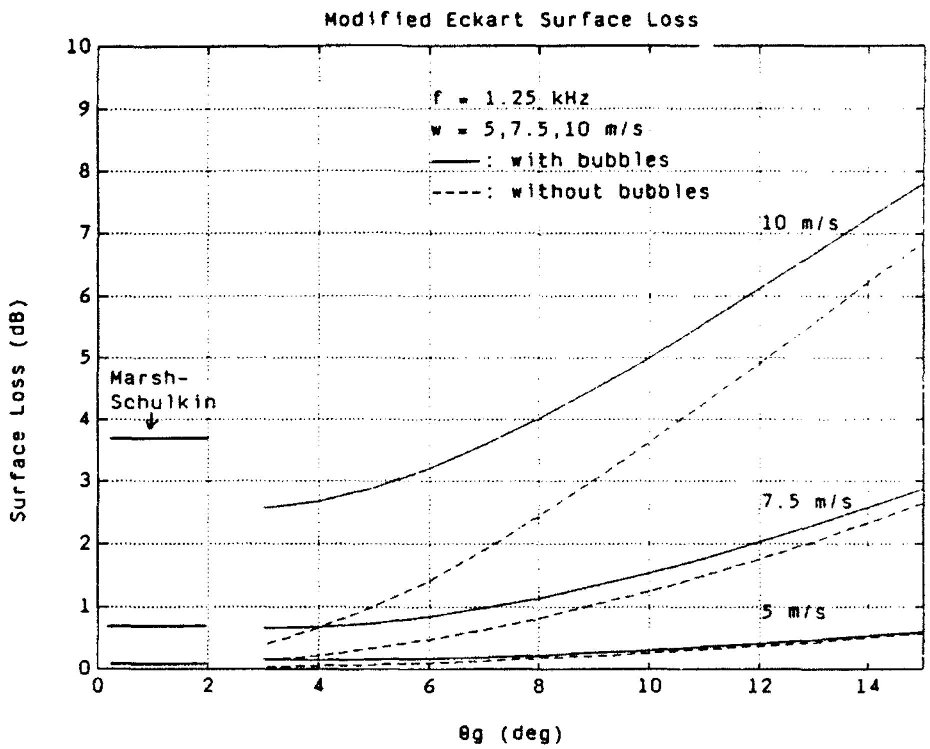
VIEWGRAPH 15



The modified Eckart surface loss model[12] was selected as an example of including SL_r in the predictions of the total "effective" near-surface loss. The Marsh-Schulkin data are plotted from $0° < \theta_g < 2°$ for wind speeds of 5, 7.5, and 10 m/s. The "effective" loss, SL, is plotted for $\theta_g > 3°$ both with and without bubbly layer effects. A flattening of the grazing angle dependence at lower grazing angles is seen, and the modeled SL approaches the Marsh-Schulkin empirical results for wind speeds below ~10 m/s. Thus, the discrepancies between the low grazing angle empirical data and the rough surface scattering theory (below 10 m/s) can be explained by inclusion of the bubbly layer refraction and attenuation mechanisms in the surface interaction problem.

VIEWGRAPH 16

NUWC



The acoustic model of Hall that addresses the effect of bubbles on near-surface propagation has been extended to a study of the generalized surface loss problem. The modeled sound speed anomaly in the bubbly layer is shown to agree with measurements at 5 kHz by Farmer and Vagle. The integrated attenuation due to the bubbly layer is shown to increase with decreasing grazing angle and increasing wind speed. The refraction effects result in an increase in the grazing angle at the surface that becomes more pronounced at higher wind speeds. The "effective" near-surface loss at low grazing angles will be greater than sea-surface interface scattering without bubbles. The "effective" near-surface loss is shown to be similar to the Marsh-Schulkin surface duct data at 1.25 kHz for moderate to low wind speeds (<10 m/s).

VIEWGRAPH 17

NUWC

SUMMARY

1. MODELING RESULTS OF SOUND SPEED ANOMALY IN A BUBBLY LAYER SHOW AGREEMENT WITH MEASUREMENTS AT 5 kHZ BY FARMER AND VAGLE. THE IMPACT OF THE SOUND SPEED ANOMALY IS TO INCREASE THE INCIDENT GRAZING ANGLE AT THE SURFACE RELATIVE TO BUBBLE-FREE WATER.

2. THE INTEGRATED BUBBLE ATTENUATION INCREASES WITH DECREASING GRAZING ANGLE AND INCREASING WIND SPEED. ATTENUATION HAS A QUADRATIC DEPENDENCE ON FREQUENCY WITH NOTABLE EFFECTS ABOVE 0.5 kHZ.

3. ATTENUATION AND REFRACTION EFFECTS DUE TO A BUBBLY LAYER RESULT IN AN INCREASE IN THE EFFECTIVE NEAR-SURFACE LOSS AT LOW GRAZING ANGLES RELATIVE TO SEA-SURFACE INTERFACE SCATTERING WITHOUT BUBBLES. LOW WIND SPEED RESULTS ARE SIMILAR TO MARSH-SCHULKIN MEASUREMENTS AT 1.25 kHZ.

REFERENCES

1. H. Medwin, "The Rough Surface and Bubble Effects on Sound Propagation in a Surface Duct," U.S. Naval Postgraduate School Report No. NPS-61Md71101A, Monterey, CA, 12 October 1971.

2. J. C. Novarini and D. R. Bruno, "Effects of the Sub-Surface Bubble Layer on Sound Propagation," Journal of the Acoustical Society of America, vol. 72, no. 2, August 1982, pp. 510–514.

3. M. V. Hall, "A Comprehensive Model of Wind-Generated Bubbles in the Ocean and Predictions of the Effects on Sound Propagation at Frequencies Up To 40 kHz," Journal of the Acoustical Society of America, vol. 86, no. 3, September 1989, pp. 1103–1117.

4. B. D. Johnson and R. C. Cooke, "Bubble Populations and Spectra in Coastal Waters: A Photographic Approach," Journal of Geophysical Research, vol. 84, no. C7, July 1979, pp. 3761–3766.

5. S. A. Thorpe, "On the Clouds of Bubbles Formed by Breaking Wind-Waves in Deep Water and Their Role in Air-Sea Gas Transfer," Philosophical Transactions of the Royal Society of London, ser. A 304, 1982, pp. 155–210.

6. H. Medwin, "Acoustical Determinations of Bubble-Size Spectra," Journal of the Acoustical Society of America, vol. 62, no. 4, October 1977, pp. 1041–1044.

7. D. M. Farmer and S. Vagle, "Waveguide Propagation of Ambient Sound in the Ocean-Surface Bubble Layer," Journal of the Acoustical Society of America, vol. 86, no. 5, November 1989, pp. 1897–1908.

8. G. V. Norton, R. S. Keiffer, and J. Novarini, "The Effect of the Background Bubble Layer on the Reverberation From a Rough Sea Surface," European Conference on Underwater Acoustics, M. Weydert, ed., September 1992.

9. H. W. Marsh and M. Schulkin, "Report on the Status of Project AMOS (Acoustic, Meteorologic, and Oceanographic Survey) 1 January 1953–31 December 1954," NUSL Report 255A, Naval Underwater Sound Laboratory, New London, CT, 1955.

10. H. Weinberg, "Application of Ray Theory to Acoustic Propagation in Horizontally Stratified Oceans," Journal of the Acoustical Society of America, vol. 58, 1975, pp. 97–109.

11. R. A. Roy and W. M. Carey, "Low Frequency Scattering From Submerged Bubble Clouds," Journal of the Acoustical Society of America, vol. 92, no. 5, November 1992, pp. 2993–2996.

12. R. M. Brown and A. R. Miller, "Geometric Optics Theory for Coherent Scattering of Microwaves From the Ocean Surface," NRL Report 7705, Naval Research Laboratory, Washington, DC, 18 June 1974.

INITIAL DISTRIBUTION LIST

Addressee	No. of Copies
NAVSEA [PMS411, 63D]	2
Johns Hopkins University/APL [B. Newhall, J. Sweeney, D. Tyler, N. Brower]	4
NRL [B. Palmer, F. Erskine, R. Gauss, P. Ogden, R. Gragg, Library]	6
NOARL [H. Chandler, B. Adams, E. Franchi (200), J. Matthews (222), R. Love (243), J. Caruthers (220), R. Field (244), Library]	8
NCCOSC [R. Smith, C. Persons (732)]	2
SCRIPPS/MPL [F. Fisher, V. Hodgkiss]	2
CNO [R. Winokur (NOP 96T)]	1
ONR/AEAS [R. Feden (124), K. Dial, E. Chaika, E. Estallotte]	4
ONR DET, Bay St. Louis [D. Small]	1
ONT [G. Kovalenko (20P21)]	1
NAVAIR [G. Persighin (NAIR 933A)]	1
ARL/UT [J. Shooter, S. Mitchell, Library]	3
NAWC [L. Allen (5033), B. Steinberg (5031)]	2
NSWC [E. Hein (U25), M. Williams]	2
NAVOCEANO [R. Merrifield (PMI), R. Christensen (OA)]	2
SAIC/McLean [R. Dicus, A. Eller]	2
SAIC/New London [F. DiNapoli]	1
BBN/New London [P. Cable, J. Bairstow]	2
BBN/Cambridge, MA [G. Shepard, D. Bosek, M. Frey, J. Heine]	4
DARPA [W. Carey]	1
ARL/PSU [D. McCammon]	1
APL/UW [C. Sienkiewicz, S. McConnell, E. Thorsos, F. Henyey, L. Crum, P. Dahl, Myamoto]	7
Kildare Corp. [R. Mellen]	1
Defence Research Establishment Pacific [D. Thomson]	1
Defence Research Establishment Atlantic [B. Franklin]	1
FWG [P. Willie, H. Baur, H. Herwig, B. Nutzel, Bibliotek]	5
DTIC	12
SACLANTCTR [Technical Director, O. Diachok, Library (2)]	4
NAVPGSCOL [Library, H. Medwin]	2